-2006

2006

IEA SMALL SOLAR POWER SYSTEMS PROJECT

1984 PROGRAM OF WORK

TEST AND EVALUATION OF CRS AND DCS PLANTS

IEA SSPS OPERATING AGENT

DEUTSCHE FORSCHUNGS- UND VERSUCHSANSTALT FÜR LUFT- UND RAUMFAHRT E.V.

~~33~~ 4010

32.1

1984

PROGRAM OF WORK

TEST AND EVALUATION OF CRS AND DCS PLANTS

Prepared by:

J.G. Martín, P. Wattiez, F. Ruiz Muñoz

Tabernas, March 1984

Approved:

(C.S. Selvage, Head of ITET)

(W. Grasse, Project Manager)

TABLE OF CONTENTS

OBJECTIVES

CRS PROGRAM OF WORK 1984

DCS PROGRAM OF WORK 1984

PLANT OPERATION AUTHORITY:
Tasks and Activities

OBJECTIVES

The predominant objective for the POW - 1984 is to collect and evaluate performance and loss data, and to evaluate proposed improvements (Optimization) to support completion of the commited deliverables; those being the reports of the CRS and DCS, as recommended by the TOAB and accepted at the twenty-fourth Executive Committee Meeting, 9 December 1983. These deliverables are:

CRS

1. Heliostat Field Performance
2. Receiver Behavior/Comparison
3. Survey of Thermal Losses
4. System Aspects/Operational Experience

DCS

1. Survey of Thermal Losses/Efficiency
2. Potential for Improvements/Optimization
3. Assessment of Effect of Third Field
4. Possibility of Automatic Control
5. Reliability, Availability, and Maintenance

"The TOAB asked the EC to take note of the fact that the objectives set forth at the beginning of the project cannot be met even during the prolonged Phase II. In CRS there will be practically no routine operation but rather a gathering and evaluation of data for the more important subsystems of the plant. Thus a comparison with DCS - which has lost its meaning anyway (no economic crossover around 500 KWe) - will not be possible."

In order to accomplish the objective of producing the deliverable reports, the CRS system must be made operational with the ASR, and the detailed test program to analyze the receiver must be completed. This test program is aimed at determining the heliostat field output, the radiation power into the receiver, and the convective, conductive, and reradiation losses of the receiver to evaluate the receiver system efficiency. At least two different methods of determining efficiency will be used, reducing the uncertainty of the final result. Transient performance of the ASR is another characteristic that must be measured and evaluated. Thermal losses and the thermal inertia of the Sodium Heat Transfer System (SHTS), including the storage tanks and steam generator, must be remeasured and re-evaluated during this year but these topics are given a low priority.

The DCS third field must be made operational so as to assess the effect of added collector area on overall system performance. In-depth measurements of thermal losses in the collector field will be completed. The receipt and installation of flow meters, which will allow rather accurate measurement of thermal flow, will surely reduce the uncertainty of thermal loss reports and will aid in determining what can be effective in an attempt to improve the systems. That is the optimization effort.

Affecting much of the evaluation team's capability is the commitment (and desire) to support the Second International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects, in Ispra, Italy, 4-8 June 1984; the International Energy Agency Workshop on the Design and Performance of Large Solar Thermal Collector Arrays, in San Diego, California, 11-13 June 1984; and to have an outstanding IEA/SSPS - CRS/DCS Workshop, which is planned for October 1984, in Tabernas, Spain. In this closing Workshop for Phase II, the project team will present a summary of the Phase II evaluation and the essence of the final reports. The Workshop will also provide an opportunity for the presentation of invited papers, updating information on related projects from other parts of the world.

CRS - POW 1984

GENERALITIES

The Program of Work (POW) sketched below reflects the SSPS goals as defined by the TOAB and the EC late in 1983. The plant is to be operated as a test facility, and one of the objectives of the work during this year, besides the testing of the plant as a power generating system, will be to gather overall and subsystem data which may be of interest for other solar thermal applications.

It is pertinent to differentiate between test programs and evaluation efforts. The Proceedings of the 1983 CRS Midterm Workshop, edited by M. Becker, represent a valuable reference document which reports on the work efforts by the OA, DFVLR, Sevillana, ITET, and experts from the participating countries, to evaluate a complex and new system. The Sulzer receiver was only part of that system - the other subsystems have not changed. To evaluate much of the CRS, in 1984, we can 'stand on the shoulders' of those first efforts.

Some operational experience with the Sulzer receiver, shortly after the 1983 workshop, has not been fully evaluated. Also, much of the ITET efforts during the latter part of 1983, and in particular the efforts of Dr. Horst Talarek, Messrs. M. Pescatore and H. Jacobs, in cooperation with the POA and Agip Nucleare, were closely related to the installation of the new receiver. An example of this is the work leading to operation procedures for receiver preheating. Preliminary thermal performance tests were also performed. Part of the ITET effort in 1984 will be based on these efforts.

It is clear that a major goal of the test plans for 1984 is to characterize the new receiver. On the other hand, the evaluation, and in particular the comparison of both receivers, must take advantage of existing data on the Sulzer receiver.

Another area of test interest will be the heliostats. Three years of operation may have affected the field. Accurate receiver characterization will depend on accurate information on field performance - and extrapolation to other solar thermal applications will be helped by a thorough understanding of what has happened to the field. Some effort was made in December 1983 and January 1984 by the POA to characterize the heliostat images optically, and some realignment was needed and was accomplished.

Tests of PCS, tank losses, etc., will not have the same priority, because much is already known about the performance of these subsystems. It is suggested that, for the sake of completeness, additional thermal loss measurement and tests will be carried out on the PCS at different loads, and at lower temperatures. However, these tests will have a low priority.

The evaluation of the performance, considered as a task which may be separate from the tests themselves, will be much more general.

The concept of the loss stair-step has guided much of the ITET evaluation in the past. It is used, to some extent, to structure this 1984 POW. However, we are slowly witnessing a paradigm shift, with the realization of the importance of inertial effects (for example, warm-up and start-up losses). 'Steady-state' design considerations may be very misleading for a solar plant. This concept, which is developing,is one which will be explored in-depth.

Some of the items relevant to this paradigm are heliostat field response ("real" and "control system-induced" delays), receiver thermal inertia, tank losses, and steam generator and PCS start-ups. Large parasitic losses (in particular, those due to trace heating) are related items, with implications in system design and scaling, and will be explored.

Low receiver thermal inertia, which seems to be desirable, may have interesting connotations as regards system transients and controls. These must be well understood to insure system integrity, and therefore these topics will be another area of concentration.

Finally, and in the context of the TOAB and EC recommendations about the transition into STAP, some experimental and computational effort will be devoted to shaping of 'flux profiles' at the receiver, both in time and configuration

The ITET makes no a priori judgement regarding the relative value of diagnostic tools such as the HFD bar, the FAS or HERMES systems, thermal loss tests, DAS evaluation, or modelling. All available tools will be used, with the hope of composing as complete a picture as possible of the plant behavior, particularly the new receiver. Due care will be taken to make each of these tools give results which are as accurate as possible, according to the state of the art. It is expected that these efforts will tend to diminish the differences between the results reached through the various methods. If these results do differ appreciably, the differences themselves will constitute an interesting new topic.

The new computer capabilities at the site cannot fail to alter the emphasis of the ITET tasks, away from the drudgery of manual data analysis, and towards major conceptual possibilities - and the drudgery of computerese.

We have noted that the ITET tasks can be classified according to whether they relate to tests or simply to data evaluation, and in terms of their priorities. They can also be structured in terms of (1) projected schedule, (2) period of time considered, (3) the subsystems (the loss stair-step and the inertial chain), and (4) the manpower (ITET, OA, and POA, and the voluntary manpower from sister institutions). They must also consider externally imposed conditions (workshops, symposia, and contractual limitations). Finally, there are (5) the commitments - the deliverables.

PROJECTED SCHEDULE

Preliminary Phase (January - February)

The ITET has started 1984 with a 'preliminary phase', during which we made an asessment of the available means, prepare the evaluation material, and plan in detail the ITET work. This phase has lasted two months. The tasks during this period were:

a) Calibration,
b) Assessment and establishment of a data processing system, and
c) Preparation of a test plan.

Details follow.

SCHEDULE 1984

	J	F	M	A	M	J	J	A	S	O	N	D
(1) Preliminary Phase	■	■										
a) Calibration	■	■										
- Identification	■											
- Calibration		■										
- HFD		■										
b) Data Processing	■	■										
- VAX Training	■		■									
- Data Handling		■										
c) POW & Preliminary Test Plan	■	■										
d) Operation												
- Normal Data-Gathering	■	■										
(2) Tests			■	■								
- Global Thermal and Efficiency			■	■								
- Transient Preparation			■									
Performance			■	■								
(3) Preliminary Evaluation					■							
- Evaluation					■							
- Operation					■							
- Normal and Missing Tests					■							
(4) Workshops												
(5) Measurement Campaign						■	■	■				
Predicted ITET Vacations						■					■	
(6) Preparation for Workshop									■			
(7) Workshop										■		
(8) Documentation											■	■

a) Calibration

The calibration effort consisted of the following:

a) Plant Sensor Points
Determination of sensor points in need of calibration (c/o M. Blanco, R. Carmona, M. Pescatore, M. Sánchez)

b) DAS Algorithms
Revision (R. Carmona, M. Sánchez)
Implementation of changes (P. Blanco, R. Carmona)

c) HFD Bar
Radiometer replacement (T. Caro, J. Ramos)
Signal amplification and transmission (T. Caro, J. Ramos)
Software modification: adaption to new receiver and program check (R. Carmona, M. Sánchez)

The establishment of the data processing system consists of

a) Software development and implementation on VAX to read 5 minute CRS tapes (M. Andersson, W. Bucher, M. Pescatore)

b) Software development for point and class summary (W. Bucher, M. Andersson, A. Brinner, W. Schiel)

The outline for the program of work was prepared by

a) J. G. Martín and R. Carmona, with input from all the ITET members and the staff from Sevillana, and under the general guidelines established by C. Selvage.

Complementing this preliminary phase, minimum modifications necessary for the thermal loss tests, such as the installation of differential thermocouples, are assessed by R. Carmona and J. Ramos. Software development to handle the heliostat field assessment is being carried out by M. Sánchez and M. Blanco.

During this phase, J. G. Martín has requested of the POA that the plant be operated 'normally' whenever possible, to gain operating experience and gather data. Limited tests, such as partial input power, could be carried out during this period at the request of individual ITET members.

<u>Second Phase</u>: First Test Campaign (March - April)

-'Steady-state' Tests

This phase will concentrate on performing tests to evaluate general field efficiency (R. Carmona), receiver efficiency and thermal losses (H. Jacobs) utilizing DAS and the HFD bars. Some of the tests being planned are the reverse flow test, closed door test, tests at different insolation levels, and different modes of plant of operation. All ITET members have been involved in the preparation and definition of these tests, which will be conducted by the POA, closely assisted by the ITET and A. de Benedetti. Suggestions from other parties are welcome.

-Transient Tests

These tests aim at evaluating the receiver transient response to develop an experimental model for the receiver and to permit an analysis of the central system. Those tests need careful review; they will be reviewed in March. The tests will be performed in April. The responsible parties for these tests will be H. Jacobs, M. Pescatore, R. Carmona, J. G. Martín, and A. de Benedetti.

During this period, evaluation of the daily plant characteristics will be under way, by M. Andersson. Global characterisitics will be studied by P. Wattiez.

Power into the cavity may be affected during this period by the soiling due to the new construction work - this will provide an opportunity to check the results from HELIOS calculations with results from Blanco and Sánchez's software development.

As an energy conservation measure, the receiver should be drained each weekend. The team will take advantage of this opportunity to make absorptance measurements.

Finally, during this period, an effort will be made to design tests and specify the equipment necessary to measure tracking errors and wind effects.

<u>Third Phase</u>: Preliminary Evaluation (May)

During this period, the results of the tests performed during March and April will be evaluated. Some tests will be continued, if necessary, and individual ITET members may suggest new tests.

Unless otherwise specified, however, the fields and the receiver will be operated 'normally'. Tests on PCS performance may be carried out during this period. The responsible person for these tests will be H. Jacobs.

The papers for the Ispra meeting will be written during this month.

Fourth Phase: Workshops (June 1-15)

Part of June will be spent by most ITET members at workshops elsewhere. The plant will be operated normally.

Fifth Phase: Measurement Campaign (June 15 - July 30)

A concentrated effort, with the participation of staff from sister institutions and the ITET will take place this month - summer solstice. It is anticipated that the HERMES caravan, and possibly some visitor from Sandia, may want to be present at this time. If it is decided to make tracking tests, they will be made during this period.

Sixth Phase (August 1 - September 1)

Only one or two ITET members will take their vacations at this time, because we recognize the need to acquire data to accomplish the evaluation and reporting effort by the end of 1984. Staff from sister institutions are encouraged to take advantage of this time-test effort to propose special tests, in consultation with ITET and POA.

Final receiver transient response and convective loss tests will be run in this time period. These are start-up and shut-down under high flux and reverse flow tests. It will not be possible to utilize data acquired after this time period in the final reports.

Preliminary consideration and/or preparation for CRS new applications (STAP) might commence this month (MHD, etc.)

Seventh Phase: Preparation of Papers for the Workshop (September)

The results of the measurement campaign, plus previous material, will be evaluated and documented in preparation for the October Workshop.

Eighth Phase: Workshop (October 1 - 15)

Final Phase: Preparation of Deliverable Documents (October 15 - December 20)

THE DELIVERABLES

One major goal of the Program of Work is to prepare the final reports on the five topics listed under Objectives. The work to be performed to meet this commitment is outlined below.

Heliostat Fields

There are many questions to be addressed in relation to the fields. Below, we list some of these, with the names of the people who may help to answer them.

- How many - and which - heliostats will have to be realigned to maintain a certain power? (F. Blanco, POA)

- What is the minimum insolation needed for operation? (R. Carmona, P. Wattiez, J. Martín, POA)

- What is the desirable washing frequency? (P. Wattiez)

- What is the actual time needed to move heliostats? (What are the limitations on field velocity due to computer blocking?) (F. Blanco, R. Carmona)

- What are the limitations in changing coordinates? (J. Ramos, P. Wattiez, POA)

- What are the other maintenance problems? (drives, cables?) (J. Ramos, P. Wattiez)

- What is the effect of wind on image? (R. Carmona, Schiel)

- What is the effect of atmospheric attenuation? (F. Blanco, INTERATOM)

- What is the effect of blocking and shadowing? Does the installation meet the specifications? (F. Blanco, M. Sanchez)

- What is the variation during the day of the flux distribution? ((Schiel, R. Carmona, J. Ramos)

- How do HELIOS results compare with those from M. Blanco and M. Sanchez's program (M. Blanco, M. Sanchez, M. Andersson)

- How do they compare with observations from HERMES and DAS? (Schiel, M. Andersson)

- What is the effect of sunshape? (R. Carmona, J. Martín)

The work for this report can be divided into the following items:

Soiling:

- reflectivity, degradation over time
- soiling characteristics
- soiling impact vs. mirror orientation and position

Mirror Degradation:

- degradation progression over time
- type of degradation
- specific investigation
- washing investigation

Heliostat Condition:

- hardware - condition over time (structure, motor, etc.)
- focalization characteristics
- weather impact on heliostat operation
- maintenance

Heliostat Field Efficiency:

- optical losses
- single heliostat behavior investigation
- HFS behavior versus meteorological conditions
- code development

Operational Strategy:

- start-up
- shut-down
- track/desteer

The following chart suggests how the responsibility may be assigned to the different items, and the support that is needed.

	INVOLVEMENT	
	ITET	Support
<u>Investigation Assignment</u>:		
- soiling	P. Wattiez POA	FHS, I. Sussemihl
- heliostat mirror degradation	P. Wattiez POA	Sandia
- heliostat condition	R. Carmona POA	University of Seville: M. Blanco M. Sanchez, INTERATOM
- heliostat field efficiency	R. Carmona M. Andersson H. Jacobs	University of Seville: M. Blanco M. Sanchez DFVLR-Stutt.
- operational strategy	J. Martín P. Wattiez	University of Seville: M. Blanco M. Sanchez POA, DFVLR-Stuttgart

P. Wattiez is in charge of coordinating the work for this report. R. Carmona will be in charge of the modelling and calculations. POA is responsible for collecting data on soiling and mirror degradation, and general heliostat conditions.

SYSTEM ASPECTS / OPERATIONAL STRATEGIES

Some items under the general category of "System Aspects" relate to a) system maintenance, b) operational strategies, and c) suitability for other solar thermal applications.

System Maintenance

The importance of maintenance and reliability on solar distributed systems has been emphasized in last year's POW. For central receivers, these items are even more important.

The identification of the main failure modes, and a modelling of the plant to ascertain availability are important goals. We expect the March application of SOLTES and STEAEC on our VAX to help in this task, but we must have the experience with the model to know if they can.

J. Ramos will make ah important contribution to this task. It continues to be desirable to establish a theoretical basis for data gathering and manipulation, and it has been suggested that the University of Arizona may help.

Operational Strategies

The goal of maximizing energy generation may be reached by an analysis of different operational strategies. H. Jacobs has been working with Sandia to understand the system simulation codes, and to transfer them to the SSPS-VAX.

Subsystem Problems That Are Valuable as an Input for the Development of New, Commercial, or Experimental CRS Applications (electricity generation and/or process heat, e.g.)

This area of concentration, stipulated by the TOAB and the EC to be a 'main goal' of the Phase II prolongation, provides a natural link to STAP. The program of work includes an emphasis on field modelling (M. Blanco, M. Sanchez) and on system modelling (H. Jacobs, R. Carmona), which help to address these problems.

Global System Performance over Long Time Periods

The intermittent nature of the power source, start-up requirements, the time shift between collection and electricity generation, and planned and unplanned outages make comparisons between different plants misleading if those plants are characterized only by their behavior at any instant or over a short time period.

For some purposes, performance data over the life of the plant may be useful. This representation, clearly, will not help to detect tends towards degradation or improvements attained because of operational experience or equipment changes. More relevantly, this representation will have to wait until the plant is permanently shut off.

To emphasize the effect of seasonal variation, a month is a reasonably long period over which the plant can be characterized. To erase or at least minimize that effect, a year should be chosen. On either of these two bases, degradation or improvements may be detected from one year to the next. Any changes in instrumentation, recalibrations, or refinements must be kept in mind when assessing any changes.

Monthly Performance

The compiled data of this category can be summarized as follows:

- collected energy, by field
- thermal energy delivered to the PCS
- electric energy, gross
- electric energy, net
- total direct solar energy
- total direct solar energy at levels above $300 W/m^2$
- total direct solar energy at levels above $500 W/m^2$
- times with no operation because of technical problems
- times with no operation because of washing
- parasitic energy consumption

The evaluation will be based on a short answer to the question, "where are the energy losses?" The answer is assumed to be that the energy losses are in:

a) the fields,
b) the air,
c) the receiver,
d) the storage,
e) the piping,
f) the power conversion system, or
g) parasitic losses.

Heliostat Field

For the field, one final result is a table, with at least five columns:

1) solar enery input from sunrise to sunset,
2) solar energy at levels above 300 W/m^2,
3) solar energy at levels above 500 W/m^2, and
4) and 5) energy radiated to the receiver.

Efficiencies, defined as a ratio of collected energy to either one of the solar energy inputs, are elements of other columns.

Other results are two tables similar to the above, with corrections for those days when the plant was not operating because of technical problems or management decisions. The difference between these two tables and the one above is a measure of system availability.

Insolation at the site has been less than was expected from earlier weather information. On the basis of the efficiencies for insolations above 300 W/m^2 and 500 W/m^2, the collected energy may be modified to indicate what would have been collected if the weather predictions had been valid. This correction, which is admittedly an approximation, illustrates how one can estimate what the performance of these systems would be at other sites.

Storage

For the storage, the results are in the form of two columns, one consisting of the energy delivered monthly to the storage tank, and one consisting of the energy delivered monthly to the power conversion system. The ratios between the two items in a row constitute a measure of storage efficiency, and the differences are losses.

Note that the losses calculated in this way may be higher than those evaluated at any one day.

Power Conversion System

Here, the results are in the form of a column for monthly energy delivered to the PCS, and a column for the gross electrical energy generated. As before, the ratios between the two are measures of efficiency, and the differences are the losses.

Parasitic Losses

This task assess the electrical energy necessary to run the CRS per month.

The calculation of the actual parasitic losses requires a judicious and cumbersome manipulation of the DAS parasitic data.

The difference between the gross electrical power generation and the parasitic consumption gives the net system generation, from which net monthly efficiencies may be calculated.

A problem arises, particularly in the monthly or yearly evaluation, because of the change in the SSPS operation goals for this year, and the fact that the plant will not be operated during weekends. The evaluators will use their judgement in interpretation of the data. It is suggested that 'mean values' will be calculated by summing results over all the daily values, and dividing them by the number of operation days.

Daily Characteristics

The cumulative data gathered for Monthly Performance (CRS/12) do not provide insight into the performance of the system at any one day.

To make up for this lack, one needs to look at the daily characteristics. Although the data will be different for every day, it is plausible to argue that one may choose 'typical' days, and that data for those days is useful in the evaluation.

Because of the seasonal variation in the plant performance, it is also reasonable to choose at least three 'typical' days, corresponding to an equinox and the solstices.

On these typical days, one must calculate

a) energy offered to the field
b) energy sent by the field to the receiver
c) energy sent by the receiver to the tank
d) energy sent by the tank to the PCS
e) total gross energy
f) total parasitic consumption

Note that the DAS evaluates all the maximum energy and power offered to the field as

irradiation X area of heliostats X 93,

where 93 is the number of heliostats. (This (key POTPWR11 in DAS) is, in fact, the 'potential power to the field').

The power that the field sends to the receiver is also calculated by DAS. DAS does the computation by taking the nominal plant operation ("design days") and correcting this number for the reflectance, the irradiance, and the number of heliostats in operation. It also multiplies this product times a normalized efficiency from a simplified look-up table for any day and hour constructed by use of HELIOS calculations. It utilizes mean values for the whole field, and it assumes that the whole field is functioning, and it therefore may be a poor approximation.

If one takes heliostats 'coherently' out of track, this is reasonable; otherwise it is not. If half of the field (say, the western half) is in operation, the look-up table makes the calculated result wrong.

M. Blanco is developing a program that yields an effective surface for the heliostat fields, and this program is complemented by M. Sanchez's program to take into account soiling over the field.

This task will require considerable computer manipulation of the data. M. Andersson has taken responsibility for this category.

RECEIVER BEHAVIOR AND COMPARISON OF THE TWO RECEIVERS

There are two main items regarding receivers in the deliverables

a) Receiver behavior, and
b) Comparison of the Two Receivers.

Receiver Behavior

Receiver efficiency and losses are a very definite aspect of receiver behavior - however, there is another deliverable called "thermal losses", where this item also fits rather nicely.

Here, "behavior" will be interpreted as receiver response. Some items of interest are:

a) response times
b) limitations imposed by safety
c) transient receiver modelling
d) start-up and shut-down
e) start-up and shut-down under high flux
f) control system
g) reverse flow
h) failure simulation
i) control system behavior

Tests to investigate these items have been defined and were used in the last tests of the Sulzer receiver (April 1983). These tasks are being modified for the ASR. H. Jacobs will be responsible for these tasks. He will be collaborating with M. Pescatore, R. Carmona, J. Martín and J. Ramos. All will be in close contact with A. de Benedetti. It may be necessary to design and/or order some additional instrumentation. These problems resolved in March.

Comparison Between the ASR and the Sulzer Receivers

The final testing of the Sulzer receiver occurred in March - April 1983. In that test period, convective loss measurements were made. Start-up and shut-down tests, under a variety of conditions, were made and other data were gathered on performance of that receiver. These data have not been completely analyzed. The specific test definitions that allow comparison between these two receivers are those used for the Sulzer receiver and modified for the ASR, as mentioned above (Receiver Behavior). Analysis of both sets of data provide comparison. H. Jacobs, in collaboration with M. Pescatore, is responsible for this item. They may be assisted by R. Carmona and M. Andersson, as appropriate.

SURVEY OF THERMAL LOSSES

Here, we must consider losses and thermal inertia in

a) piping, tanks, and PCS,
b) receiver, and
c) parasitics.

Piping, Tanks, and PCS

H. Jacobs has done a considerable amount of work on these items, and he is responsible for this task. It is possible that R. Carmona may make contributions to this item.

Receiver

Under this item, we must consider

a) efficiency tests,
b) loss tests (closed door, reverse flow), and
c) convection and radiation losses.

H. Jacobs is in charge of this task. He may be helped by R. Carmona and M. Pescatore. He will also interact with P. Wattiez, M. Blanco, and M. Sánchez to the extent that measures of energy sent from the field may be needed.

Interactions with colleagues from other institutions (Kraabel, Sandia; Schiel, DFVLR; etc.) will be encouraged and defined at a later date.

Parasitics

This, and notably the trace heating, are extremely important items for molten systems.

One must address such questions as how many hours must the plant be operated so that the net energy balance is zero, how do losses scale with plant size, and what design changes would be recommendable for future plants.

F. Ruiz, H. Jacobs, and R. Carmona may help to answer these questions.

ITET INVOLVEMENT - CRS

ITET Members

M. Andersson, Theorells, Stockholm	Software Development (Daily Performance) (Meteo)
R. Carmona, ADESA, Sevilla	Modelling (Controls) Transients and Controls POW Heliostat Field Modelling
H. Jacobs, INTERATOM, B	System Simulation Modelling Thermal Losses and Inertia Comparison of Receivers PCS Receiver Performance
J. Martín, University of Lowell, Massachusetts	POW Systems New Applications
M. Pescatore, EIR, Zurich	Comparison of Receivers (Thermal Losses)
C. S. Selvage, Sandia, Livermore	General Guidelines Inertia STAP Coordination
P. Wattiez, SSPS, Brussels	Global Performance Heliostat Field

Fellows

M. Blanco, University of Seville	Heliostat Controls
M. Sanchez, University of Seville	General Engineering Field Data
I. Sussemihl,	Heliostats Soiling

Experts

A. de Benedetti, Agipnucleare, Milan	Receiver Safety Receiver Transient Perfor- mance

DELIVERABLES	COAUTHORS	SUPPORTING INSTITUTIONS
Heliostat Field	P. Wattiez R. Carmona M. Blanco M. Sanchez I. Sussemihl	DFVLR - Stuttgart
Operational Experience	P. Wattiez M. Andersson	
Receiver		
a) behavior	H. Jacobs M. Pescatore J. Martín J. Ramos	(A. de Benedetti) DFVLR - Stuttgart
b) comparison of 2 receivers	H. Jacobs M. Pescatore	Sandia
Thermal Losses	H. Jacobs	Sandia DFVLR - Stuttgart INTERATOM Sevillana
System Aspects		
a) general	R. Carmona J. Martín J. Ramos	University of Seville Sandia
b) new	J. Martín	
c) degradation	R. Carmona P. Wattiez	electronic and chemical firms

DCS - POW 1984

INTRODUCTION

The operation of the plant by the Plant Operation Authority (POA) will be based on test requirements established by the ITET and POA to provide data which will allow the evaluation of plant operation, for presentation at the October Workshop, as well as the five deliverable reports that are required by the end of 1984. They are

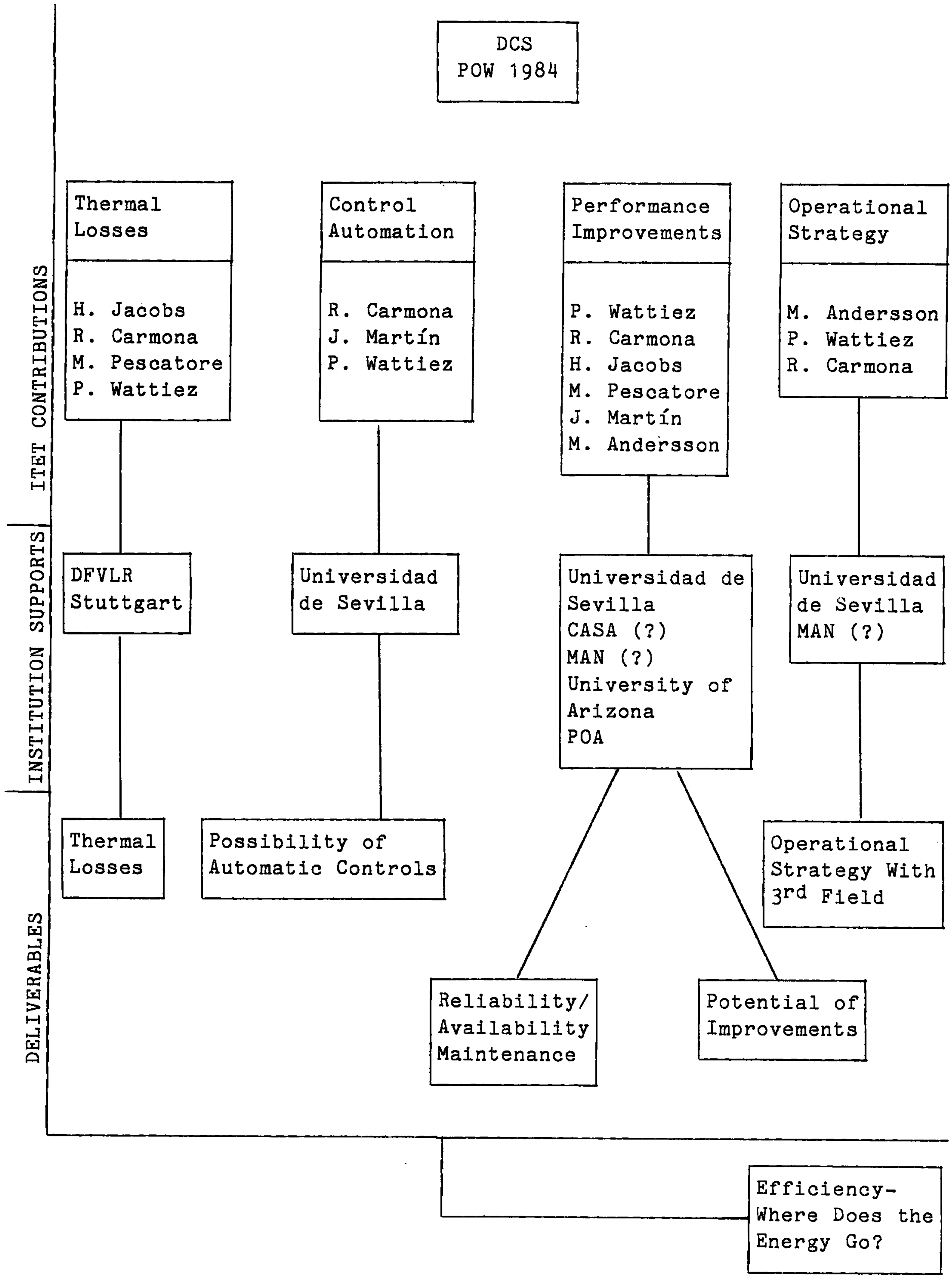
1. Survey of thermal Losses/Efficiency
2. Potential for Improvements/Optimization
3. Assessment of Effect of Third Field
4. Possibility of Automatic Control
5. Reliability, Availability, and Maintenance

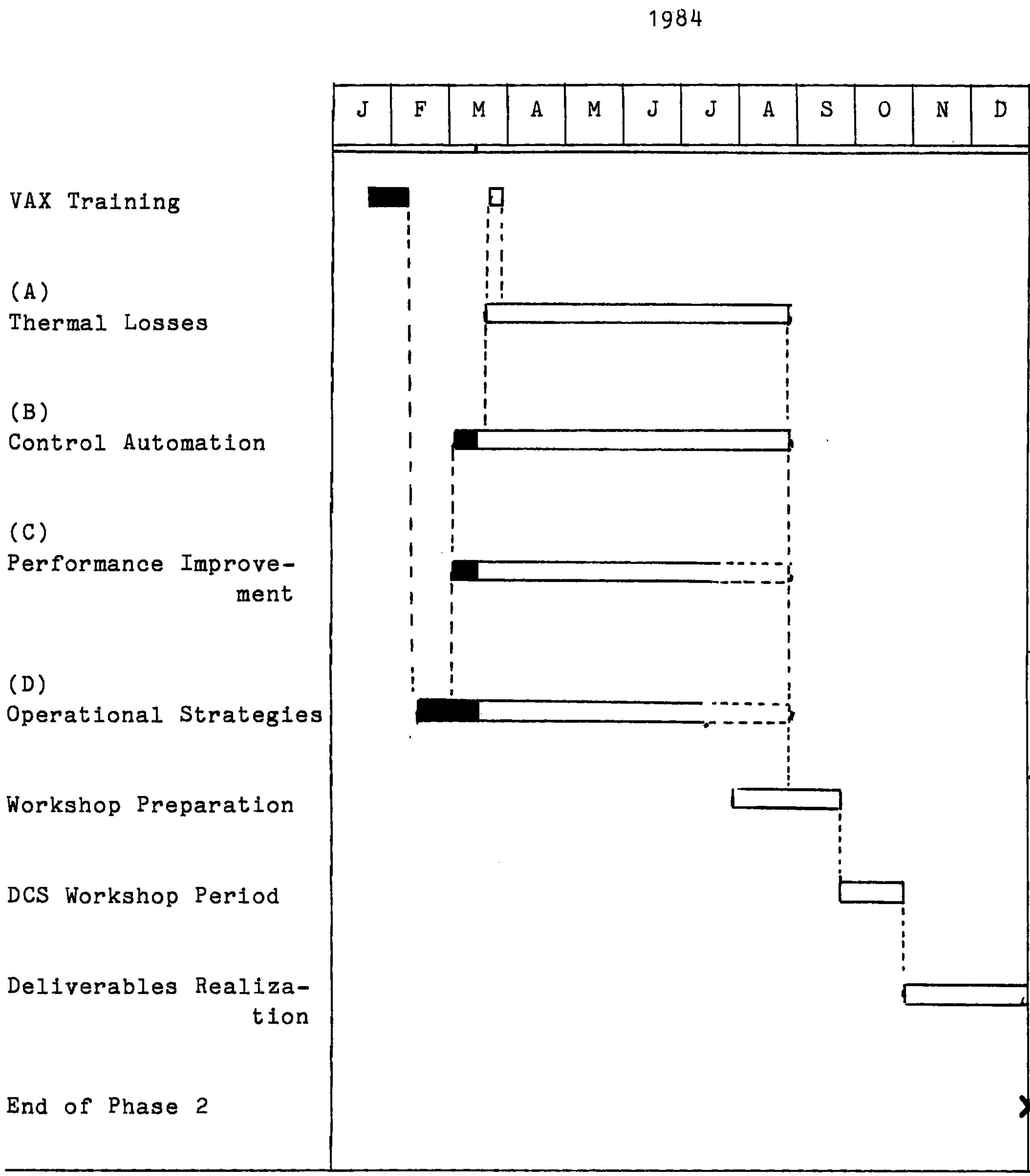
Program Orientation

"How Are the Solar Parts of the DCS Best Used?"

After two years of plant operation aimed at electrical production, the 1984 DCS Test and Evaluation Program will concentrate on behavioral study of the solar components and subsystems - namely the collector fields and storage - as interated parts; taking into account the existing plant hardware configurations and specifications.

For analytical purposes, the study of optimization actions and recommendations for the subsystems will be applied to the evaluation of the potential of the entire DCS plant, on the basis of the actual "behavior and working conditions" of the conventional system - PCS and EPGS. This will be accomplished by direct and/or indirect actions, e.g., in-situ tests and simulations (SESAM). (See Figure 1).

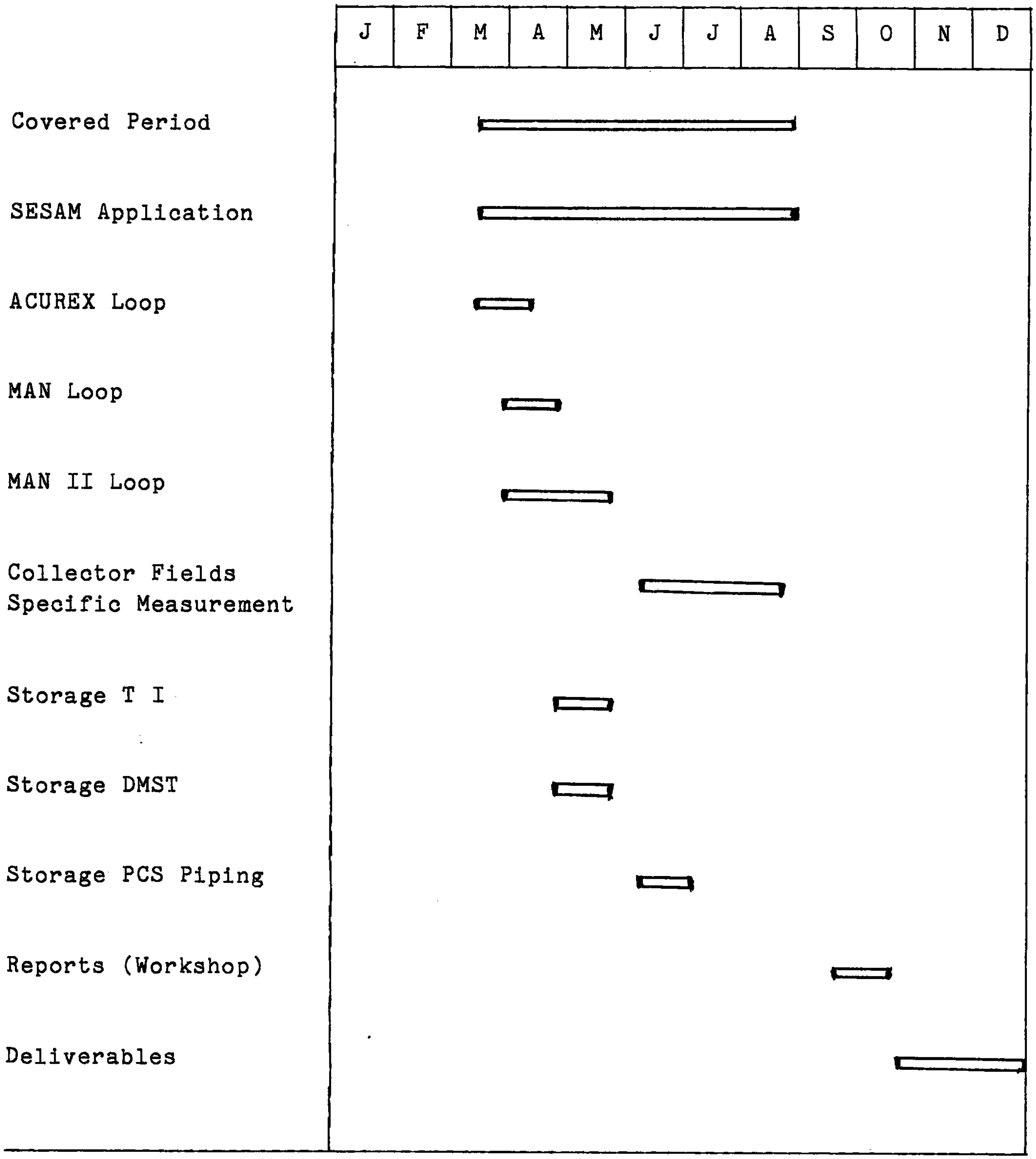

DCS
POW 1984
ITET CONTRIBUTIONS
INSTITUTION SUPPORTS
DELIVERABLES
Thermal Losses
H. Jacobs
R. Carmona
M. Pescatore
P. Wattiez
Control Automation
R. Carmona
J. Martín
P. Wattiez
Performance Improvements
P. Wattiez
R. Carmona
H. Jacobs
M. Pescatore
J. Martín
M. Andersson
Operational Strategy
M. Andersson
P. Wattiez
R. Carmona
DFVLR Stuttgart
Universidad de Sevilla
Universidad de Sevilla
CASA (?)
MAN (?)
University of Arizona
POA
Universidad de Sevilla
MAN (?)
Thermal Losses
Possibility of Automatic Controls
Operational Strategy With 3rd Field
Reliability/ Availability Maintenance
Potential of Improvements
Efficiency- Where Does the Energy Go?



DCS - POW 1984

GENERAL TIME SCHEDULE

1984



DCS - POW 1984

(A) THERMAL LOSSES INVESTIGATIONS

TIME SCHEDULE

(A) <u>Thermal Losses - Test Listing</u>

* <u>ACUREX Module</u> + thermal inertia
  Loop
  Field

* <u>MAN I Module</u> + thermal inertia
  Loop
  Field

* <u>MAN II Module</u> + thermal inertia
  Loop
  Field

* <u>Main Field Inlet Piping</u> : ACUREX
  MAN I
  MAN II

* <u>Main Field Outlet Piping</u> : ACUREX
  MAN I
  MAN II

* <u>Storage</u> : T 1
  DMST

* <u>Storage</u> : PCS Piping

* <u>Storage</u> : DMST - T 1 Piping
  T 1 - DMST Piping

<u>Warm-up</u>

When the field is not operating, it losses thermal energy; consequently, at start-up it is relatively cold. The solar energy that is collected between start-up and the time when the oil reaches the chosen operating temperature is spent compensating for the field losses <u>and</u> in heating up oil pipes, insulation, etc. If the field "thermal inertia" is large, these losses may be substantial.

These losses have been calculated by estimating the actual solar energy collected during start-up by multiplying the solar energy offered to each field by each field optical efficiency, which has been evaluated independently. Part of this energy has been spent in heating the field, and part has been lost through radiation, convection, and conduction mechanisms while doing so. The results of this calculation have been reported.

An alternative method may provide a check on these results: the heat capacity of the field may be calculated on the basis of configuration, component masses, and heat capacities. Thermal losses as a function of some field characteristic temperature can be evaluated separately. Then, knowing the temperature of the oil as a function of time, it is in principle possible to calculate the energy investment directly. This method is also particularly suited for computer modelling; the team proposes to attempt it in connection with the modelling work.

Warming up losses are extremely relevant from the point of view of control and to define operating strategies. In the case of the DCS field, they are also very high; one of the main lessons to be drawn from the SSPS project is the importance of a low thermal inertia.

The flow meters requested some time ago have recently been received and are being installed in collector loops. They will allow a more accurate determination of specific loop flow and, with the accurate measure of temperature along the pipe in the loops, a more accurate measure of thermal losses and thermal inertia. The effect of application of some proposed thermal improvements can then be assessed and the data provided as an input to the SESAM program in potential for improvement.

B2. Control Automation

The goal of the automation program will be the design and implementation of a system that permits automatic operation of the fields. The system is based on a minicomputer with a scanner for each field.

This phase itself is divided into four stages:

a) Determination and execution of the procedure for field start-up and shut-down. This procedure will depend on the hour, the insolation, lowest storage tank thermocline temperature, wind speed, and the oil level and nitrogen pressure alarms.

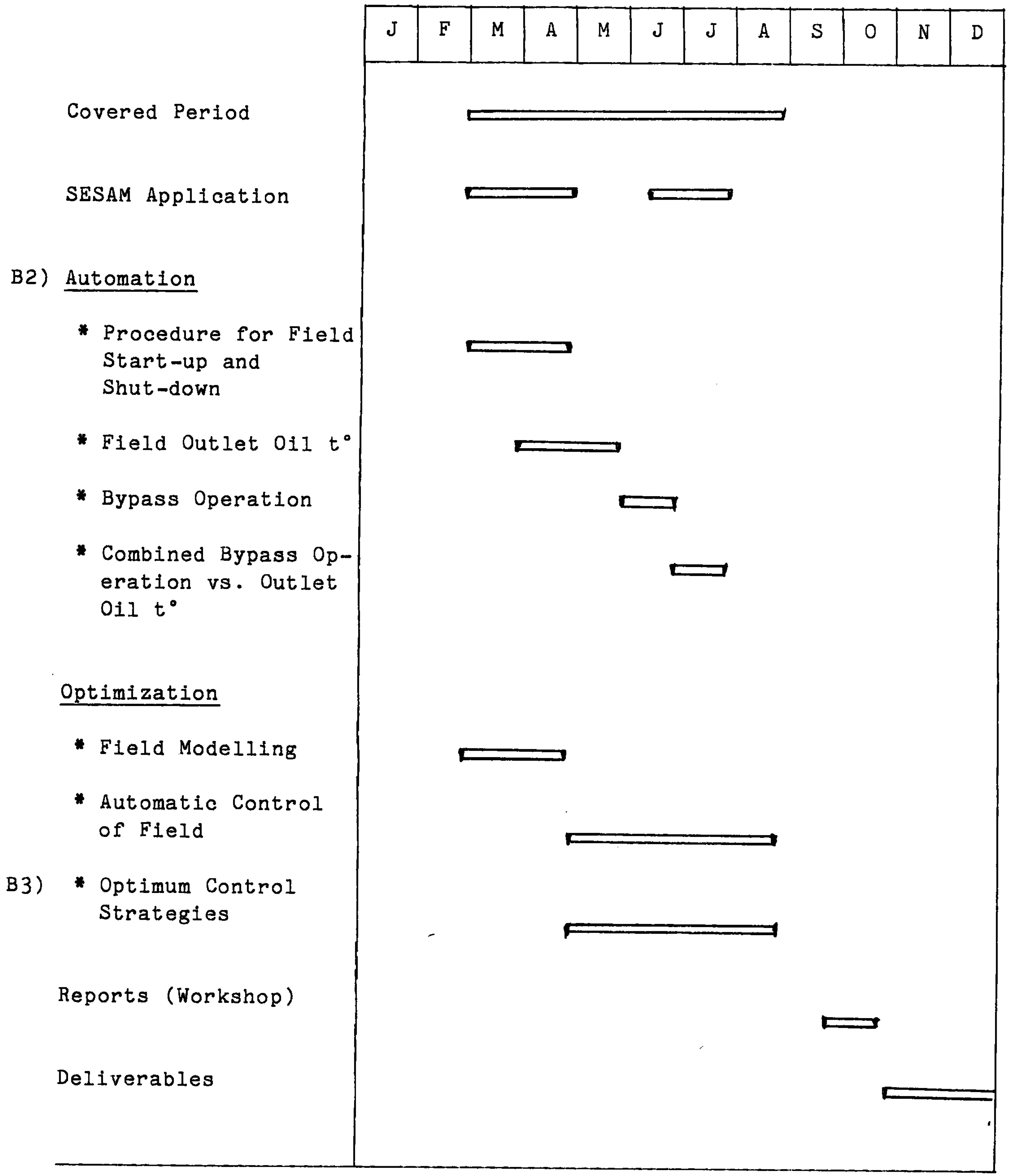
b) Control of oil temperature at the field outlet by manipulation of the flow rate via a control equation implemented by software in the computer. This equation depends on the insolation and the inlet oil temperature to the field. It has been suggested that this equation could be the same as is now implemented in analog form in the Control room panel; however, the feedback component of the control system will be of the proportional-integral-derivative (PID) type instead of the current PI type.

c) Control of the bypass valve so as to recirculate the oil during warm-up. Again, this is a digital variation of the present practice: this change permits the testing of different bypass strategies.

d) Control of the bypass valve so as to help maintain the oil temperature at the field inlet within an acceptable predetermined range. This is a new function of the proposed system: it aims at improving field performance during transients. At this stage, taking advantage of the flexibility afforded by the digital implementation performed in (1b), the flow control equation itself will be changed by adding higher or lower terms in the temperature to represent more accurately the field response.

Because of insufficient funds, the automation program must become an investigative program using the on-site HP-85 and scanner (used primarily for the CRS-HFD measurement). These experimentation results could then be applied in theory to the remaining system parts. This can be accomplished with the aid of SESAM-VAX.

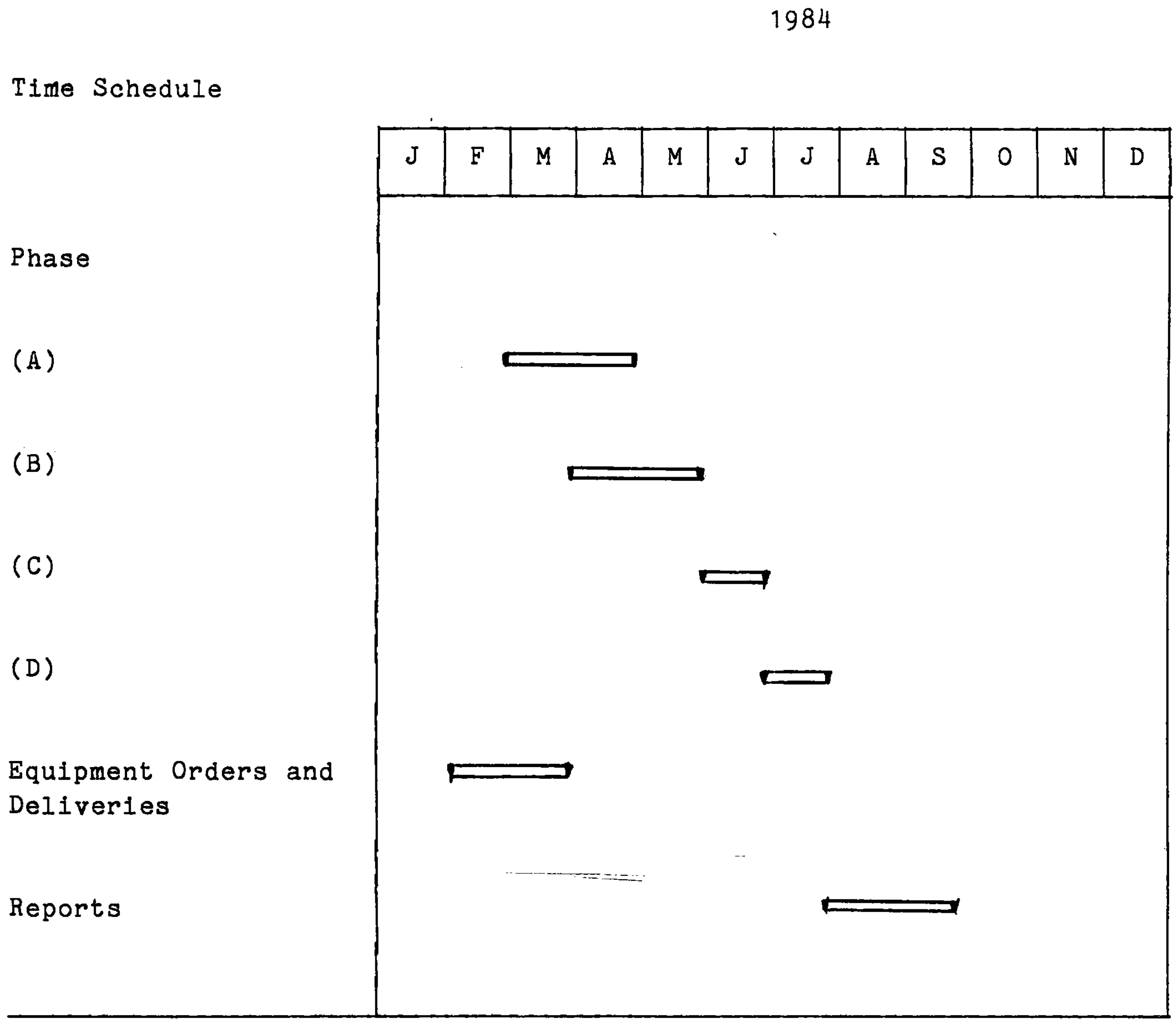
1984



DCS - POW 1984

(B) CONTROL AUTOMATION INVESTIGATIONS

Time Schedule



<u>Equipment</u>

- computer, e.g., HP-85
- scanner, e.g., HP-3497
- mirror electronic components
- pipe, insulation, 2 manual valves, 2 temperature sensors

<u>Personnel</u> (Universidad de Sevilla)

- R. Carmona
- J. Ramos
- M. Blanco

B3. Optimization

Operational Strategy

The goal of the optimization phase is to define performance criteria for the DCS fields and to apply "state of the art" control techniques to satisfy these criteria.

This phase is divided into the following stages:

a) Modelling of the Field

Based on experimental data of the model parameters, validation of the SESAM code through comparison of computer simulations with real field data.

SESAM-DCS is a computer code developed under contract by Belgonucleaire, and aimed at simulating the behavior of the SSPS DCS plant. It features detailed thermohydraulic modelling, including thermal inertia and a realistic modelling of the regulation and control system of the plant.

Much of the planned modelling work and optimization analysis centers on the use of this code, which can be run on the Apple II desk computer and on the VAX mainframe computer.

Mats Andersson is the ITET member who is the contact person for SESAM: it is hoped that the program will allow the plant operator to choose stategies and to cope with prescribed production patterns.

Aside from this, a modest modelling effort has been carried out by ITET memebers R. Carmona and L. Castillo, which had the goal of predicting the energy collected by the field, using solar radiation data every five minutes.

The utilization of more general computer codes which are not designed specifically for this system would help in establishing benchmark calculations. SOLTES, developed by Sandia National Laboratories, is an evident example of such a code. An agreement with Sandia, whereby H. Jacobs spent two weeks at Sandia for familiarization with this program, was very helpful and could lead to application to the DCS if appropriate.

b) State of the Art Control Optimization

The ultimate purpose of this stage is to arrive at the best automatic control strategy for the field. Using the model developed, different control optimization techniques will be simulated in a separate computer.

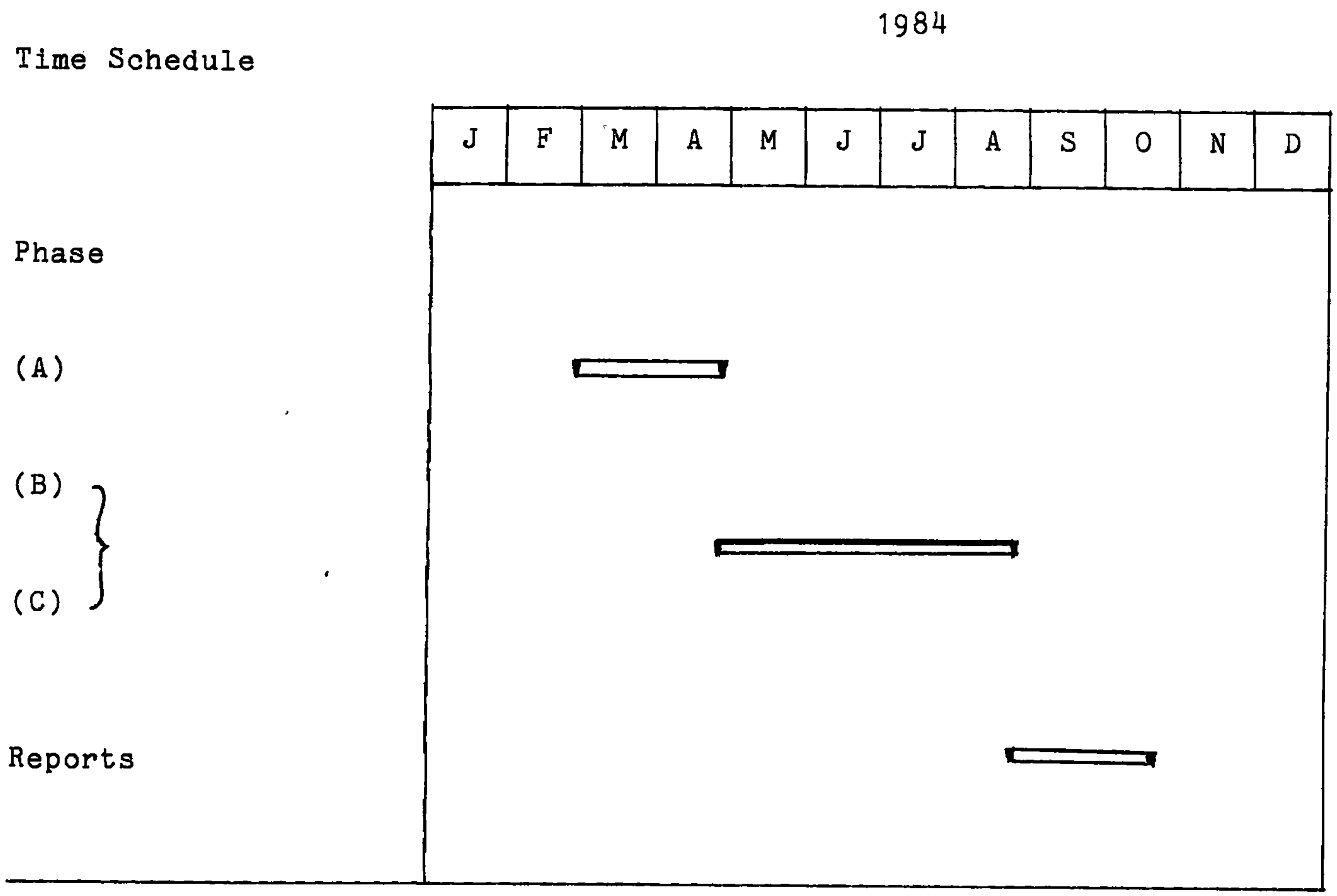
One such technique will be based on optimal control using some functions of the field energy output and outlet temperature variance as optimization indexes. Another technique will be based on adaptive control, characterizing the "forgetting factor variable".

The product of this phase shall be a preliminary selection of the control strategy that will lead to the best field performance in terms of the optimization criteria chosen.

c) Implementation of Optimum Strategies

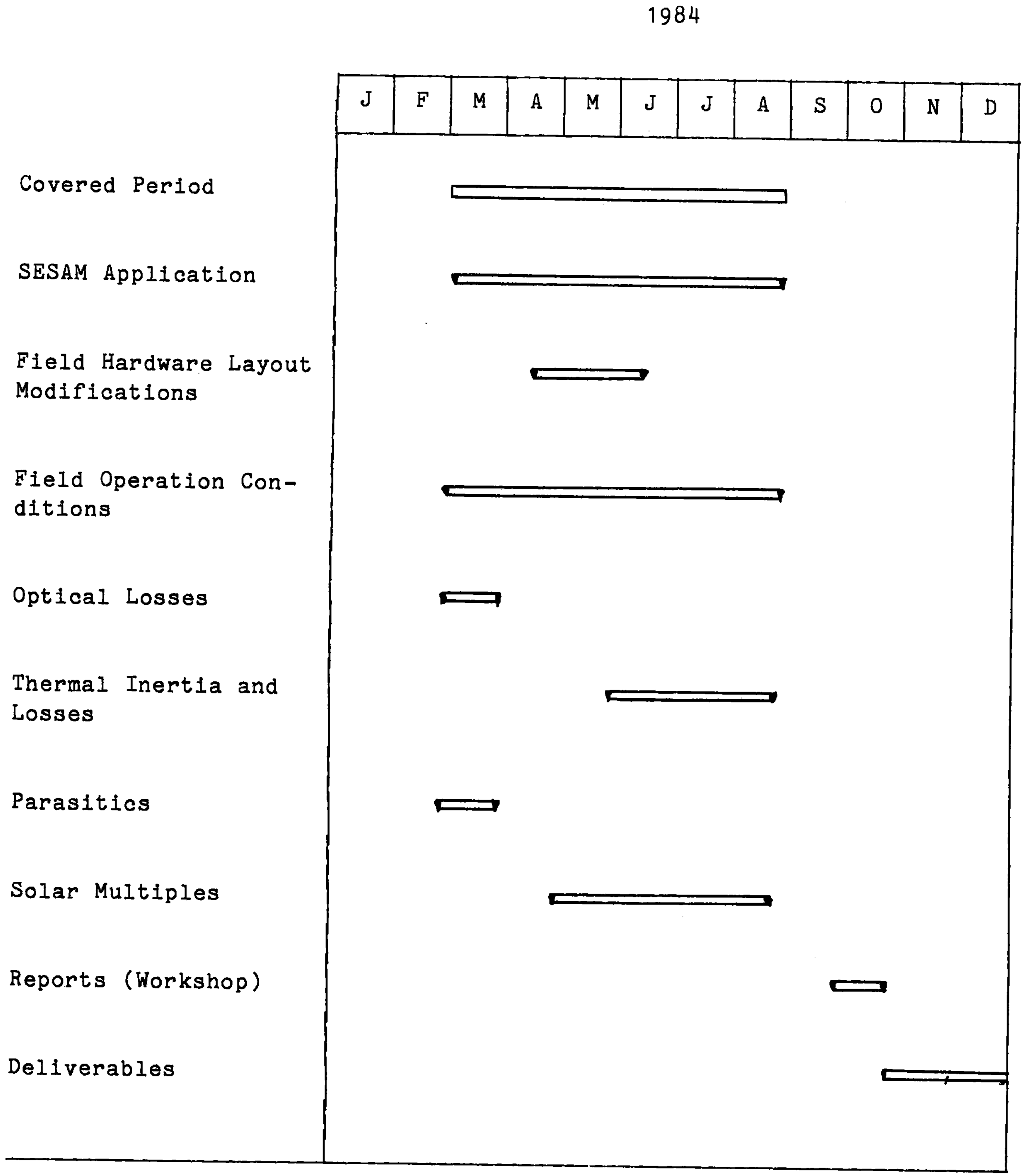
In this stage, the control strategies defined above will be implemented on the minicomputer on site (see Control Test), to study the actual field response.

Time Schedule



<u>Personnel</u> (Universidad de Sevilla)

- 1 engineer, 6 months full-time
- 2 engineer-students, 6 months



DCS - POW 1984

(C) PERFORMANCE IMPROVEMENT INVESTIGATIONS

TIME SCHEDULE

C. Performance Improvements Criteria

As shown by the Energy Flow Diagram 1983 (see Figure 2) there are many possibilities for improvement of the DCS. One of the first objectives of the optimization phase is to examine each of the loss elements of the concerned system for physical and real modifications. This should lead to a higher estimate for efficiency of the entire improved system.

As a result of time, personnel, and financial limitations, all optimization or modification ideas, suggestions, or recommendations will not be possible. A selection will be made according to the following criteria:

- system efficiency impact (daily and monthly)
- hardware and software modifications (accessibility and timing)
- cost
- time to implement

An evaluation of the more impressive optimization suggestions will be made by use of the simulation program, SESAM, evaluating their impacts on the system and subsystem behavior.

The selected criteria, as assessed using SESAM, and the above selection criteria will determine the executable tests or improvements in the established time frame (see Figure 1).

Improvement Areas

Limited to the collector fields and storage subsystems, the optimization investigations will cover both subsystems and their interfaces with the environmental conditions and plant configurations. The major items of the operational strategies are

- system and components behavior
  - a) thermal losses and criteria for improvement
  - b) energy consumption (parasitics)
- control system
- hardware configuration
- operational strategy
- additional investigation areas

The "optimization task force" has produced a collection of suggestions and recommendations for optimization, which are presented in the following:

PERFORMANCE IMPROVEMENT TEST LISTING

Subsystem and Components Behavior

- Determine for a module, row, and loop of the three collector fields, the

  a) thermal losses and inertia
  b) energy consumption
  c) operational limits (temperature, pressure, irradiance levels)
  d) optical losses

- Behavior of storge tanks at several oil temperatures

Control System

- Digitize the control for automatic operation of a single collector, loop, and field, for automatic control.

- Automation of start-up and shut-down for an optimization of loop and field behavior under various irradiance levels.

- Optimization of DCS collector field behavior by automatic control to reduce thermal and optical losses to a minimum.

Hardware Configuration

- Utilization of MAN and ACUREX fields respectively, for low and high temperatures.

- MAN Field:
  a) connection as loop in two consecutive rows.
  b) bypass the buffer tank
  c) digitize the field control system for automatic control
  d) disconnection of the flow control valve

- ACUREX Field:
  a) bypass the buffer tank
  b) digitize the field control system for automatic control
  c) disconnection of flow valve

- New MAN field and DMST: an operating strategy to reduce the warming of the two other fields by
  - a) oil-preheating concept
  - b) preheating energy stored in advance

- Collector field orientation (ACUREX) - impact assessed with the simulation program (SESAM)

Additional Investigation Areas

Additional investigations were proposed in the following areas:

- Statistical analysis of cloud presence during field operation, and the impact on their behavior.

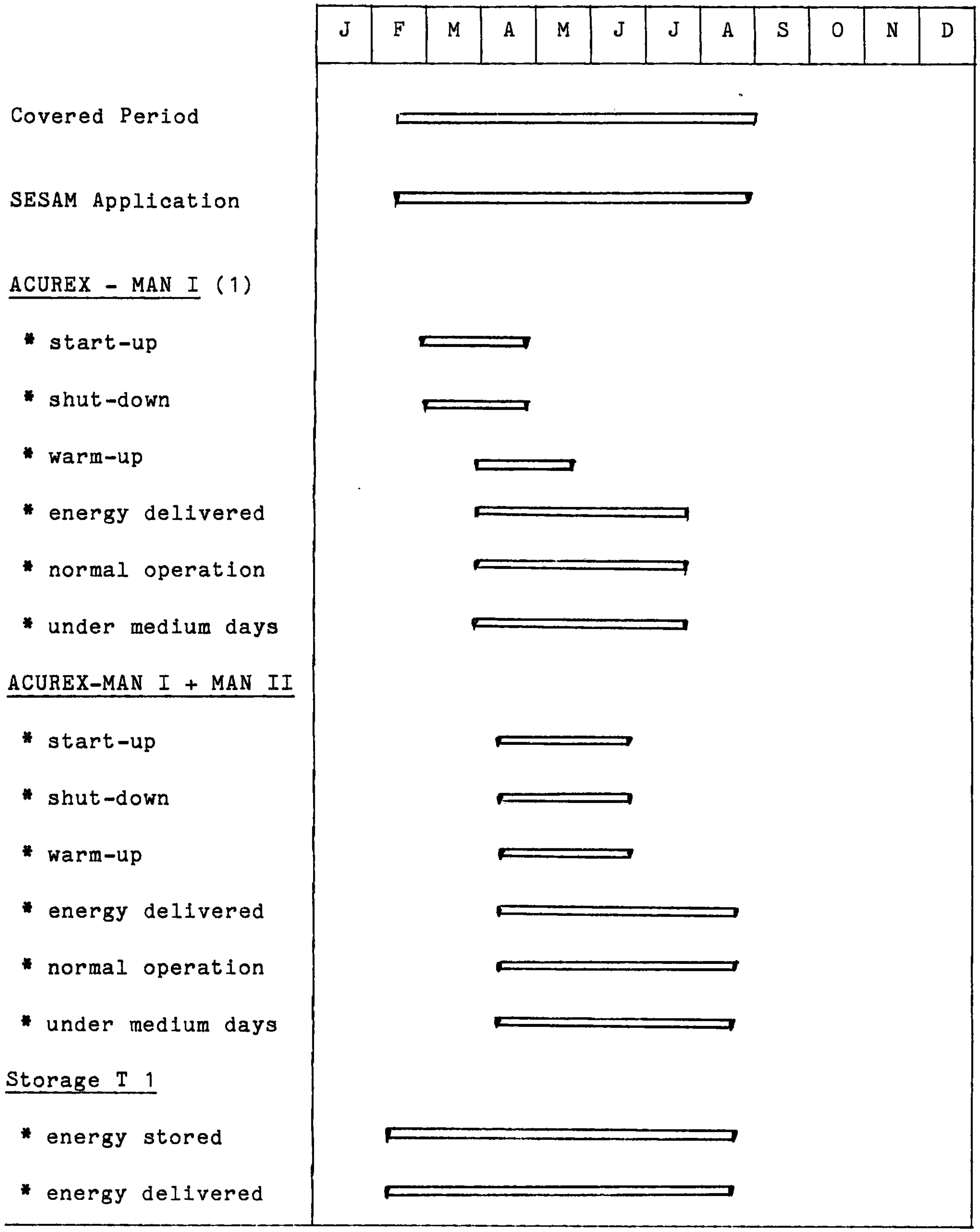
- DCS availability - recorded procedure

- Impact on plant behavior as a result of the increased collector field.

- Energy balance of storage and collector field on a yearly, monthly, and daily basis; taking into account

  - a) m^2 of activated collectors
  - b) solar irradiance
  - c) others

1984



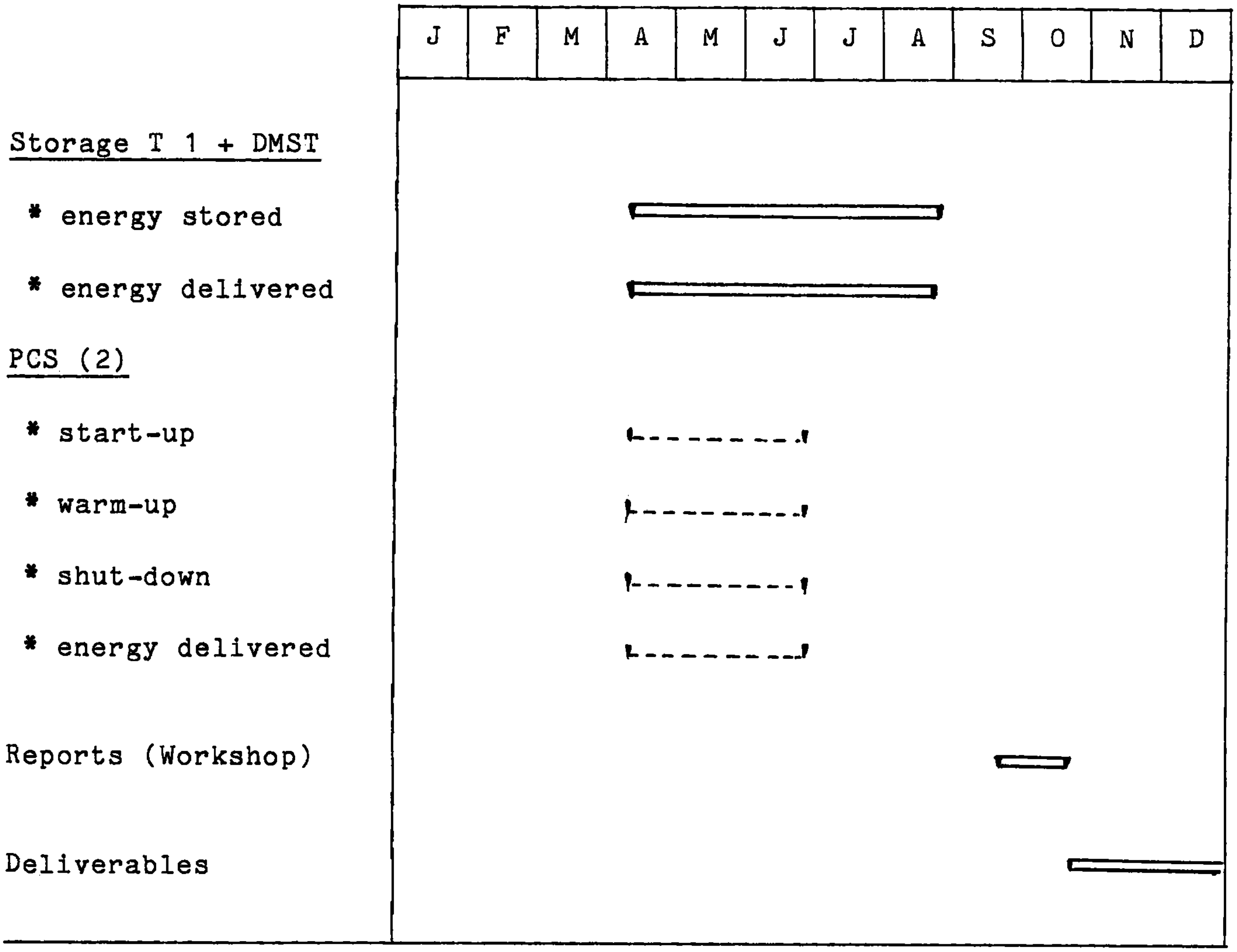
(1) see Control Automation

DCS - POW 1984

(D) OPERATIONAL STRATEGY STATUS INVESTIGATIONS

TIME SCHEDULE

1984



(2) second priority

DCS - POW 1984

(D) OPERATIONAL STRATEGY STATUS INVESTIGATIONS

TIME SCHEDULE

Operation Strategies

Although interaction with the grid has not been a concern in the operation of the plant - the amount of power generated is too small - there is considerable room for decision-making on operational stategies.

Decisions have to be made on:

- when to start-up and shut-down the fields,
- when to start the PCS, and
- the load profile.

To increase the hours of operation, tests have been made to operate the plant at temperatures below the design temperature (down to about 280°) and at minimum flows of 2 liter/second (down from the early 3.5 liter/second). It has been possible to extend operation by 30 to 45 minutes, adding approximately 200 kWh to the collected energy.

The fields are normally shut-down whenever the outlet temperature at minimum flow drops below the operating temperature. It is possible that the fields should be operated further, so long as the value of the net energy collected is larger than the additional parasitic consumption. Clearly, more work is needed in this area: for example, the MAN field may operate two hours longer than the ACUREX field, but about 1.2 MWh of solar energy is offered to the MAN field while it is not operating. R. Carmona and P. Wattiez are working on this subject.

At present, the DCS solar multiple is too low to permit storage and full electrical generation simultaneously. In fact, energy is normally stored until the tank capacity is reached, at which point electrical generation starts. The tank would be depleted in about 1.5 hours, but continued collection allows considerably longer operation. Partial load operation is possible if the load is not too low or the low load operation is not maintained too long, in which case the water chemistry is affected. Load shaping permits longer operation times.

If the tank storage capacity is not reached before the end of the day, the operator has to decide whether to start the PCS or not, saving energy for the next day. The relative advantage of each strategy will depend on the PCS start-up losses, and the overnight thermal losses from the tank. These decisions will be helped by the ongoing effort of H. Jacobs and M. Andersson.

Operation on Cloudy and Partly Cloudy Days

How much energy can be collected on a partly cloudy day? On alternative solar power concepts - i.e., photovoltaics - on a partly cloudy day when the total insolation is 50% of that of a representative clear day, the total energy generated is probably close to 50%. This is not necessarily the case of a DCS: it is important to quantify this statement, and to formulate operating strategies for these days.

This work has been initiated by R. Carmona and P. Wattiez.

Transient Behavior

This theme is closely related to the problem of control. What is the effect, for example, of the passages of clouds over the fields? How does the outlet temperature vary, and how does this variation affect the plant perfomance? Some tests have been run on this, which is work which interests R. Carmona and H. Jacobs.

ITET Involvement

Name	Area
J. Martín	Optics Potential of Improvement Control
R. Carmona	Control Operation Strategy Optimization
H. Jacobs	Thermal Losses Energy Balance
M. Andersson	Simulation Code Operational Strategy
M. Pescatore	Thermal Losses Energy Balance
P. Wattiez	Optics Potential of Improvement Operational Strategy

Deliverables

As mentioned in the minutes of the 10th TOAB meeting, the DCS deliverables for 1984 are planned to be the following:

Deliverables	Coauthors	Supporting Institution
Thermal Losses/ Efficiency	P. Wattiez J. Martín H. Jacobs R. Carmona	DFVLR - Stuttgart
Potential for Improvements	Combined ITET Efforts	CASA (?)
Assessment of Effect of Third Field	M. Andersson P. Wattiez	MAN (?)
Possibility of Automatic Control	R. Carmona J. Martín	Universidad de Sevilla
Reliability, Availability, and Maintenance	P. Wattiez J. Ramos	University of Arizona Sevillana POA

Plan of Evaluation Support

Area	Type of Support Needed	Potential Contact Organization
Optical Losses *Reflectance *Transmittance *Absorptance *Emittance *Solar Ray Plots *Degradation -Delamination -Deformation -Tracking -Coatings	Pers: optic specialist Time: end of 84 Equip: specific instrumentation	POA
Thermal Losses *MAN Supplement *Collector Efficiency *Piping Losses *Thermal Loss Modeling	Pers: heat-transfer expert Time: end of 84 Equip: specific instrumentation	DFVLR Stuttgart POA
Control *Automation *Optimization *MAN Supplement	Pers:) see) Automa- Time:) tion) (Annex Equip:) B)	Universidad de Sevilla POA
Global Characteristics *Increment of Solar Multiple (MAN Supplement)	Pers: engineer Time: end of 84	MAN
Operational Strategies *Three Fields and Two Tanks	Pers; engineer Time: end of 84	Universidad de Sevilla POA MAN
Storage *New Tank	Pers: heat-transfer expert Time: end of 84	EST CO. POA
Potential of Improvement *Collector Field *PCS	Pers: Solar Expert Time: end of 84	CASA POA

Area	Support Request	Potential Contact Organization
Reliability Availability Maintenance	Pers: experts Time: 6 months	University of Arizona POA

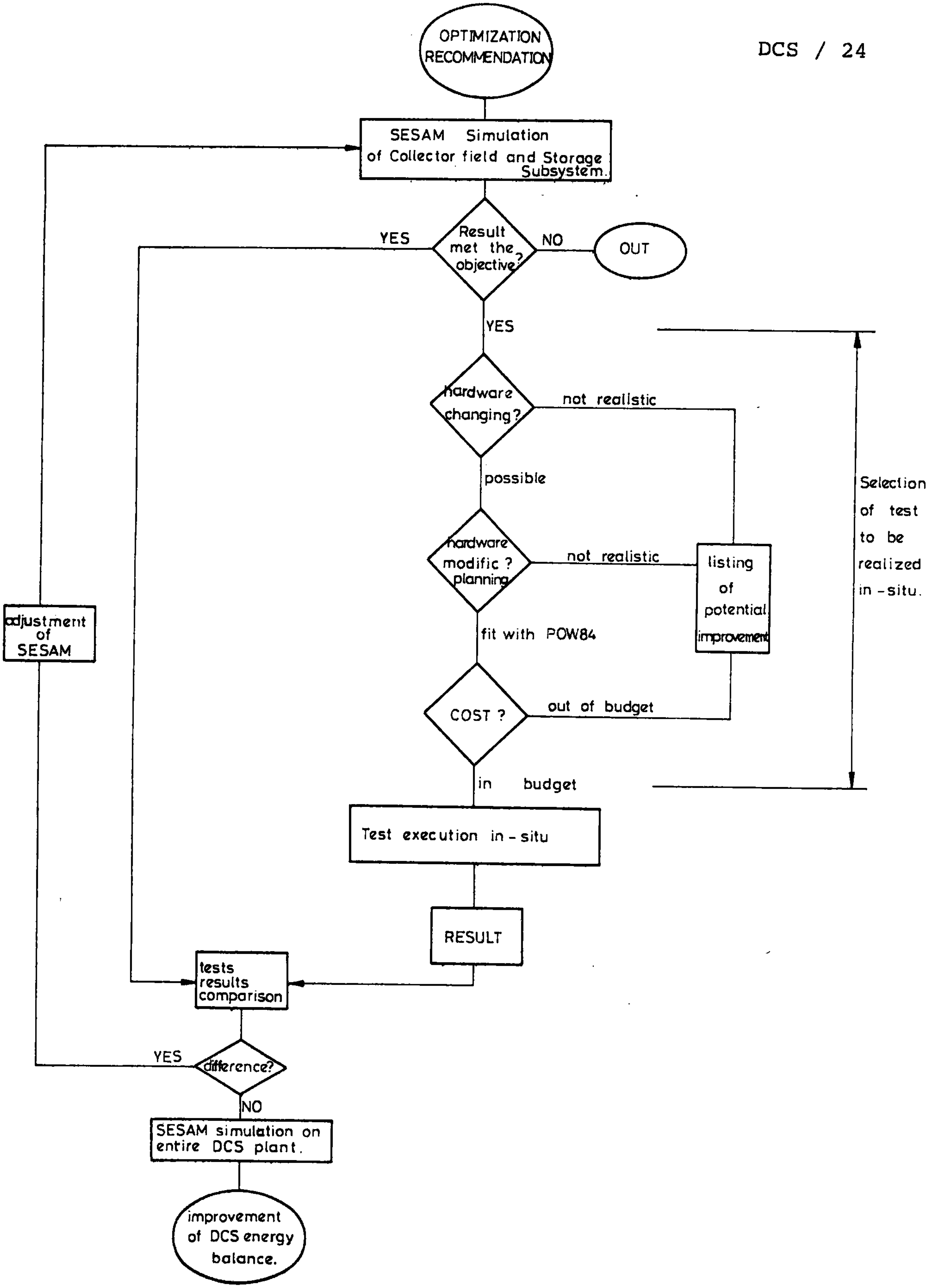
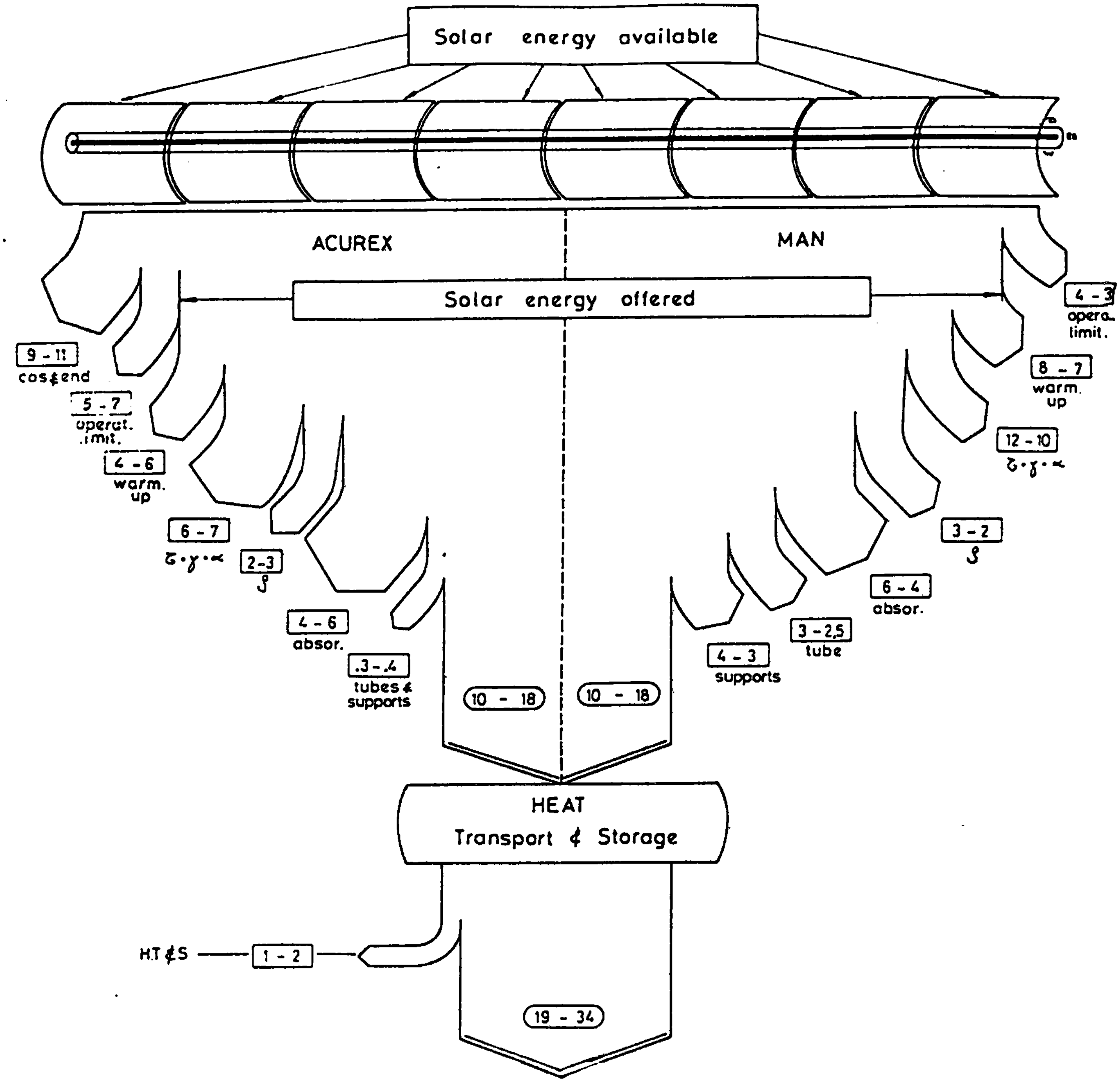


Fig. 1

DCS - POW 84
flow diagram



Solar energy available
ACUREX
MAN
Solar energy offered
9 - 11
cos ¢ end
5 - 7
operat. limit.
4 - 6
warm. up
6 - 7
2 - 3
4 - 6
absor.
.3 - .4
tubes ¢ supports
10 - 18
10 - 18
4 - 3
opera. limit.
8 - 7
warm. up
12 - 10
3 - 2
6 - 4
absor.
3 - 2,5
tube
4 - 3
supports
HEAT
Transport ¢ Storage
H.T ¢ S
1 - 2
19 - 34

Fig: 2

PLANT OPERATION AUTHORITY

PROGRAM OF WORK 1984

Table of Contents

1. Introduction
2. Objectives
3. POA's Organization
4. Supervision, Test & Engineering Activities
5. POA Test Proposals
6. Deliverables

1. INTRODUCTION

Following the recommendations of the TOAB, the operational team has been reorganized to fulfil the new objectives set for the SSPS Stage II extension. Experience will be gathered at the same time that will help to define the operational needs for the STAP.

The shift in SSPS objectives, changing the nature of the SSPS Plant from a demonstration plant to a test facility has produced two main changes in the operational structure:

a) Reduction of the operation time from seven to five days per week,

b) Establishment of the Supervision, Test and Engineering Group.

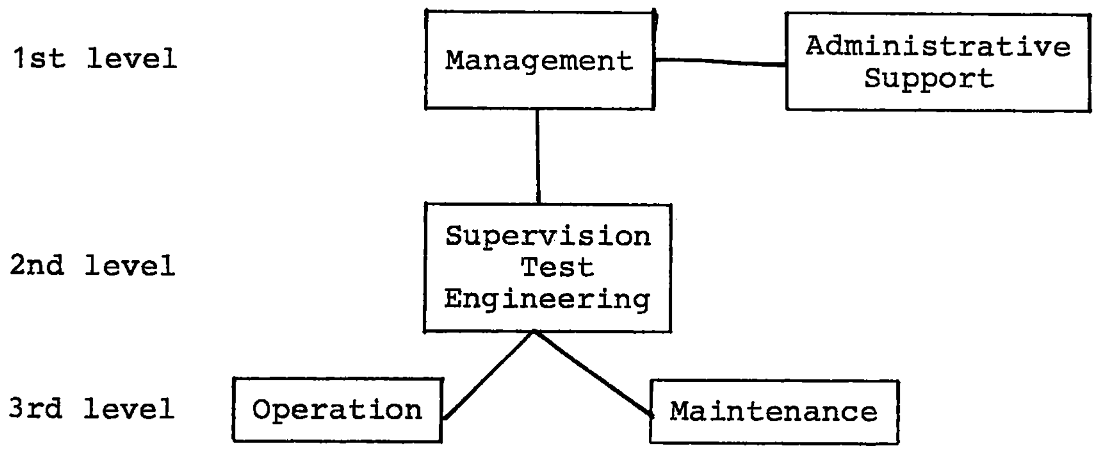
2. OBJECTIVES

The Plant will be operated having as a first priority, the accomplishment of the Test and Evaluation Program as proposed in the Program of Work for 1984.

In addition to this point, the P.O.A. will perform within the limits of its technical capability and available budget, all improvements and modifications that may increase the operational efficiency of the Plant.

3. POA's ORGANIZATION

3.1 Organizational Chart



3.2 Personnel

Management	
Plant Director	1
Administration	
Secretaries	2
Helper	1
Supervision, Test and Engineering	
Engineers	5
Operation	
Operators	7
Watchers	4
Maintenance	
Electronic foreman	1
Electric foremen	2
Mechanical foremen	2
Helpers	3
Total	28

3.3 Working System and Timetable

3.3.1 The personnel included in the Management, Administrative, Engineering and Maintenance crews work in split-working days from Monday to Friday, and from 8:30 a.m. to 5:30 p.m.

3.3.2 The personnel included in the operational crew work is as in the following table:

From Monday to Friday

SHIFT	TIME	C R S	D C S
1st shift	7 am - 3 pm	1 Operator 1 Watcher	1 Operator 1 Watcher
2nd shift	3 pm - 11 pm	1 Operator 1 Watcher	1 Operator 1 Watcher
3rd shift	11 pm - 7 am	1 Operator	

Saturday and Sunday

1st shift 2nd shift 3rd shift	7 am - 3 pm 3 pm - 11 pm 11 pm - 7 am	1 Operator

4. SUPERVISION, TEST AND ENGINEERING ACTIVITIES

The following is a list of the activities for the P.O.A. Test and Engineering Group:

4.1 D C S

4.1.1 DCS Supplement

- -Personnel training
- -Support during the acceptance tests
- -Support in the elaboration of the Operational Strategy

4.1.2 MAN Field

- -Actions to eliminate all current problems
- -Design and construction of a test bed for the tracking electronics

4.1.3 Field Control

- -Support in the implementation of the new digital control

4.2 C R S

4.2.1 ASR

-Modifications and improvements in the instrumentation and control systems

4.2.2 Heliostat Field

-Improvements to the generation of the Sun Presence signal by the HAC computer

-Correction of the tracking error

4.2.3 Heat Flux Measurement

-Support for test, calibration and improvement of current and future systems

4.3 General

4.3.1 Reliability

-Improved data collection to allow for RAM anaylsis

4.3.2 Optimization

-Cooperation in the process of decision and implementation of proposed improvements

4.3.3 I.T.E.T.

-Collaboration as direct as possible in the Test Program

4.3.4 Solar Heating and Cooling

-Support for design and implementation

4.3.5 GAST

-Collaboration in the Test Program activities performed in the SSPS Plant

5. POA TEST PROPOSALS

The POA will propose to the ITET for its consideration, a set of tests oriented to optimize the operational strategy in terms of daily electric energy output.

6. DELIVERABLES

At the end of the SSPS Stage II, the POA will supply a report condensing the lessons learned from its experience of more than 3 years of plant operation.

DISTRIBUTION LIST

1) MEMBERS OF THE EXECUTIVE COMMITTEE AND T+O ADVISORY BOARD	L. GUTIERREZ (EC CHAIRMAN)	
	G. FANINGER	(A)
	H. KLEINRATH	(A)
	T. VIJVERMANN	(B)
	A. MICHEL	(B)
	P. KESSELRING	(CH)
	C.-J. WINTER	(D)
	M. FISCHER	(D)
	C. SÁNCHEZ LÓPEZ	(E)
	C. PENCHE SELGUEROSO	(E)
	C. ORTÍZ ROSES	(E)
	CH. ARONIS (E.N. CARABATEAS)	(GR)
	F. REALE	(I)
	G. ELIAS	(I)
	G. BEER	(I)
	B. FINNSTRÖM	(S)
	J. HOLMBERG	(S)
	K.T. CHERIAN	(USA)
	C.S. SELVAGE	(USA)
2) IEA SECRETARIAT	J.P. HEINZELMANN	
3) BMFT / KFA-PLE	H. KLEIN	
	F.J. FRIEDRICH	
4) D F V L R	R. KÖHNE	
	J. NITSCH	
	W. SCHIEL	
	K. SCHREITMÜLLER	
5) INSTITUTO PARA LA DIVERSIFICACIÓN Y AHORRO DE LA ENERGÍA	A. DEL RÍO DISDIER	
	J. AVELLANER LACAR	
	E. RIEDEL	
6) SANDIA LABS	A. BAKER	
7) COMPAÑÍA SEVILLANA DE ELECTRICIDAD S.A.	J.M. GONZÁLEZ MORENO	
	F. RUÍZ MUÑOZ	
8) OPERATING AGENT (COLOGNE + ALMERÍA INTERNATIONAL TEST AND EVALUATION TEAM		